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THE FLASH SPECTRUM.

BY S. A. MITCHELL.

Advances in the "new astronomy" were very rapid after 1859, when KIRCHHOFF formulated the laws of spectrum analysis. In a communication to the Royal Society, April 23, 1868, HUGGINS gave the first tangible results in the movements of approach and recession between the Earth and the stars, thus confirming the Doppler-Fizeau principle, announced about a quarter of a century earlier. In the same year, on August 18th, the spectroscope was first applied to a study of the Sun during a total eclipse. We are all of us familiar with JANSSEN'S observations of the spectrum of prominences, with the fact that he saw these "red flames" the next day without an eclipse, with their independent discovery by LOCKYER, and with the communication by the two distinguished scientists of their results to the same meeting of the French Academy. These discoveries make a most notable chapter in the history of astrophysics.

KIRCHHOFF'S laws tell us that the dark lines of the solar spectrum are caused by the absorption of light of definite wavelengths as the rays pass through the metallic vapors that surround the Sun. These vapors are at a high temperature, and if the more intense light of the Sun could be cut off by some means, these gases ought to shine of their own light, and give their spectrum of bright lines. Since these gases cause the absorption spectrum, the lines that appear bright in the emission spectrum ought to have the same positions as the lines that appear dark in the Fraunhofer spectrum, or, in other words, one spectrum is just the "reversal" of the other. Thus reasoned Professor YOUNG. Since the Moon cuts off the light of the Sun at a total eclipse, Professor YOUNG, before the eclipse of

1870, foretold the reversal of the spectrum at the instant the Sun was entirely covered up by the Moon, *i. e.* at the beginning of totality. We can perhaps imagine the feeling of joy experienced by him in having his investigations verified by seeing the bright lines flash out for a few seconds at the beginning and ending of the total phase. Indeed, a great triumph for the mind of man!

But how many of the lines were reversed? It seemed that the flash spectrum matched line for line the Fraunhofer spectrum; certainly the more prominent lines appeared dark in one spectrum and bright in the other; but it was impossible to determine in a few seconds whether *all* the lines of the absorption spectrum were seen also in the emission spectrum, or whether there were any lines in the latter that did not appear in the former. This question could be settled only by obtaining a permanent record of the flash spectrum by photography, which was accomplished for the first time in 1893 by FOWLER, in West Africa, and again in 1896 by SHACKLETON, in Novaya Zembla. From investigations of the photographs of these two eclipses, LOCKYER has found that in the region between F and K only three and eight per cent, respectively, of the lines in the solar spectrum were found in the flash. ("Recent and Coming Eclipses," p. 111.) He also found that the intensities of the lines of the two spectra were by no means the same, and decided, not, indeed, without excellent reasons, that the one spectrum was not the reversal of the other, and that the flash must therefore be due to some other cause than the shining out of the "reversing layer," which, by absorption, causes the Fraunhofer lines. LOCKYER, however, counted the number of lines in the solar spectrum from ROWLAND'S maps, obtained by a much more powerful instrument than had been used at either eclipse,—a test, therefore, which was hardly a fair one.

The differences in intensity of the two spectra were indeed hard to explain. LOCKYER found that certain lines which appeared stronger in the flash than in the solar spectrum also were stronger in the spark than in the arc, and thought that "clearly, then, the chromosphere, as photographed in the eclipses of 1893 and 1896, is a region of high temperature, in which there is a corresponding simplification of spectrum, as compared with the cooler region in which the Fraunhofer absorption is produced" (*loc. cit.*, p. 111); but he does not make perfectly clear how it is that, when we go from the lower layers of the Fraunhofer spectrum *away* from the Sun to the higher region of the flash spectrum, we reach a higher temperature, instead of a cooler one, as we would naturally expect.

The important spectroscopic investigations at the Indian eclipse of 1898 were those of EVERSHED and LOCKYER, both of whom used prismatic cameras. Although the wave-lengths of the flash lines given by the two observers agree very well, the conclusions drawn from them differ as widely as possible. LOCKYER explains the differences of intensity, as he did in the two preceding eclipses, by saying that the Fraunhofer spectrum is connected with the temperature of the arc, while the flash is more nearly related to that of the spark. EVERSHED, on the other hand, accepts YOUNG's original explanation of the "reversing layer," and gives as the cause of the intensity-variations the *heights* to which the vapors ascend above the Sun's surface.

The cause of these widely different explanations is found in the impossibility of always correctly identifying the flash lines. ROWLAND, by using concave gratings of high dispersion, has given a standard of excellence for the Fraunhofer lines, to which as yet, for the flash spectrum, we have been able to approach only very distantly. Photographs of the flash have been taken with a much smaller dispersion than that of ROWLAND's maps, with the focus at times none too exact, so that it is not at all surprising that individual flash lines have been assigned by different observers to different elements. It is only through better determination of wave-lengths that we will arrive at the correct interpretation of the solar phenomena.

The only results of the eclipse of 1900 so far published are those of FROST (*Astrophysical Journal,* Vol. 12, 307-351, 1900). His investigations do not show to him any foundation for the stress LOCKYER places on "enhanced" lines in connection with the flash, but, on the other hand, lead him to again confirm YOUNG's investigations.

In view of these problems of great interest to astronomers, it was with great pleasure that the writer accepted the invitation to become a member of the expedition sent out by the U. S. Naval Observatory to view the Sumatra eclipse of May 18, 1901. The party consisted of eleven—six members of the observatory staff and five invited guests. The former included Professor A. N. SKINNER, U. S. N., in charge of the expedition; Professor W. S. EICHELBERGER, U. S. N.; Professor F. B. LITTELL, U. S. N.; Mr. G. H. PETERS, Mr. W. W. DINWIDDIE, and Mr. L. E. JEWELL, now of the Johns Hopkins University. The guests of the party were Professor E. E. BARNARD, of Yerkes Observatory; Dr. W. J. HUMPHREYS and Mr. H. D. CURTIS, of the University of Virginia; Dr. N. E. GILBERT, of Hobart College; and the writer.

A second party, from the Smithsonian Institution, consisting of Professor C. G. ABBOT and his assistant, Mr. P. A. DRAPER, accompanied the Naval Observatory members, the two parties sailing together from San Francisco on February 16th. Government steamers carried the expeditions to their destination,—the United States army transport " Sheridan " via Honolulu to Manila, the United States steamer "General Alava" from Manila to Sumatra, which was reached April 4th.

Before arriving in the island it had been decided to occupy two stations for observations on the eclipse; one, Solok, near the central line of totality; the other, Fort de Kock, near the northern edge of the Moon's shadow-path.

When we arrived in the East Indies it was soon found that clouds were likely to be exceedingly troublesome, for at no time during the day was the sky perfectly clear. In view of this, it was thought best to subdivide the party at Solok, and a third station was selected at Sawah Loento, twenty miles beyond Solok, at the terminus of the " Staatsspoorweg op Sumatra," the government railroad running inland from Padang. At Sawah Loento were already located Mr. and Mrs. H. F. NEWALL, of Cambridge, England, and a party from the Massachusetts Institute of Technology, under the direction of Professor BURTON.

The eclipse station was situated 1,250 feet above sea-level, the latitude and longitude being:—

$$0^\circ\ 41'\ 52''\ \text{South},$$
$$100^\circ\ 46'\ 40''\ \text{or}\ 6^{\text{h}}\ 43^{\text{m}}\ 6^{\text{s}}.7\ \text{East}.$$

The duration of totality was calculated at five minutes and forty-one seconds.

The main work at Sawah Loento was spectroscopic. The spectroscope consisted of a Rowland flat grating of 15,000 lines per inch, having a ruled surface of 3½×5 inches, and a quartz lens of 3⅜ inches aperture and 72 inches focal length, made by BRASHEAR, the whole apparatus belonging to the Naval Observatory. The grating was employed in the manner which gives a normal spectrum, which is the case when the diffracted ray leaves the grating perpendicularly, or the angle of diffraction is zero. The attempt was made to photograph the first order spectrum from λ 3000 to λ 6000, hence with λ 4500 at the center of the plates.

The day of the eclipse dawned clear, and our hopes were that these favorable conditions would remain till after totality, which occurred shortly after noon. First contact was observed in a perfectly cloudless sky, but soon after this clouds began to gather, and a quarter of an hour before second contact the sky was completely overcast.

The disappearing crescent of the Sun was watched by a binocular, before one half of which was arranged a small plane grating in such a way that with one eye the spectrum could be seen, with the other the Sun itself. With this, shortly before the time of second contact, bright lines were seen for a few seconds at F and H and in several places in the green and yellow, but these disappeared almost immediately,—the Sun being completely hidden by clouds,—and the first flash passed without our being able to see it.

Towards the middle of totality conditions became a trifle better, so that it was possible to see, through clouds, the corona extending for about half a diameter from the Sun, and with the small spectroscope the "coronium" line could be seen quite distinctly. During no time of the five minutes and forty-one seconds of totality was an unclouded view of the corona obtained, but, nevertheless, the second flash was seen beautifully. An hour after the total phase the clouds cleared away, and a perfect sky remained for the rest of the day.

Altogether eight plates—or, rather, films—were exposed, —one before and one just after totality for the cusp spectrum, one at first and one at second flash, and four during the total phase, with exposures of 12^s, 120^s, 90^s, and 45^s, respectively.

The first plate was taken ten seconds before the computed time of the second contact, and was exposed for one half second. It shows the cusp spectrum and about sixty lines between F and H.

As noted above, the clouds thickened at an inopportune time, with the result that nothing appears on the plate exposed for the flash. The four plates exposed during totality show continuous spectrum of a width equal to the diameter of the Sun, and extending from about λ 4900 to λ 3400, also bright lines of hydrogen from $H\beta$ to $H\eta$ and the helium line λ 4471.6 undoubtedly due to the upper chromosphere.

The second flash seemed fully exposed in spite of the clouds.

An exposure was made as soon after totality as possible,—probably five seconds after third contact,—for the cusp spectrum. An exposure of one half second was given, the plate closely resembling that made before second contact.

For some reason the spectra were not all of them in perfect focus. As absorption lines suffer from this defect more than bright lines, it was found practically impossible to measure the cusp spectra. For wave-lengths, we are therefore confined to one plate,—that of the second flash. This was exposed for three seconds, the exposure being stopped at the first reappearance of the Sun.

The peculiarities of this photograph of the flash are twofold: (1) The normal spectrum, and (2) the great dispersion.

On the plate the distance from F to H is 95.4^{mm}, and as the spectrum is normal, 1^{mm} therefore corresponds to a difference of wave-length of 9.37 tenth-meters, or 1 tenth-meter corresponds to a dispersion of about 0.1^{mm}. This dispersion is about one fifth of that obtained with the ordinary Rowland mounting with a grating of 20,000 lines and radius of 21½ feet.

The plate was measured with one of the Repsold machines belonging to the Columbia University Observatory, by comparing the position of the spectrum lines directly with a millimeter scale. Measures with this machine can be made directly to 0.005^{mm}, and by estimation to 0.0005^{mm}, *i. e.* to 0.005 λ; the sharpness of the lines, however, did not permit them to be carried to quite this degree of exactness.

Although the spectrum was not in the most perfect focus, in view of the great dispersion measures could be made with a high degree of accuracy. Wave-lengths were determined by taking well-defined standards properly distributed, whose wave-lengths were taken from ROWLAND'S table of standard wave-lengths. Three independent measures of the plate were made.

Second and third contacts were not 180° apart, and the instrument was set up to make a compromise between the two positions. This is the reason for the inclination of the lines of the flash.

Those who have attempted to identify the bright lines with ROWLAND'S map know the difficulty of this undertaking. Great care was exercised in the determinations of the wave-lengths, and in the comparisons with ROWLAND'S tables. For the flash an arbitrary scale of intensities was taken, where 0 means a line seen with certainty, 10 the strongest line, 00 denotes a line seen with difficulty.

In comparing wave-lengths of the flash spectrum with those of the solar spectrum, it is necessary to bear in mind two points: first, we are dealing with a dispersion of about one fifth of ROWLAND'S, with the focus not so exact, and therefore it will be impossible to separate in the flash the counterparts of close dark solar lines; second, the emission and absorption lines are formed at different heights above the Sun's surface, and the emission lines will, as a result, be shifted (in this flash) towards the violet.

The focus is best between F and H, and for the present purpose this region only will be considered. Neglecting *H* and *He* lines and those lines identified with groups, 374 lines were measured in the flash between F and H. Ninety-one of these were unidentified, and 283 were identified with lines in the solar spectrum.

Two points are immediately noticed in comparing the two spectra: first, for each and every element, the brighter the solar line the brighter the flash line corresponding to it; second, the intensities of the solar lines which correspond to a line of given brightness in the flash differ with different metals. *Fe* and *Ni* lines of intensity 5, *Ti, Sc,* and *V* lines of intensity 2 are identified with flash lines of equal strength. These differences for the various elements were so marked that in order to arrive at their significance, and hence draw some conclusions regarding the "reversing layer," comparisons were made between the flash and the solar spectrum.

Although we cannot directly compare the intensities of the bright lines of the flash (scale 0-10) with those of the dark lines given in ROWLAND'S tables (scale 1-1000), we arrive at certain theoretical considerations if we compare the ratios of the average intensities of the different elements,—that is, $\frac{\text{Flash intensities}}{\text{Solar intensities}}$, and also the ratio of the number of lines of each element identified to the whole number of solar lines for that metal. Forming these ratios and arranging them, we are at once struck with the systematic variations not only in the ratio of intensities, but also in the percentage of lines identified.

The meaning of these systematic differences will be understood if we consider these ratios in combination with the atomic weights of the various elements, as is done in the following table, where also are put down the number of lines of the flash due to each metal:—

GROUP I. LINES STRONG IN FLASH AND IN SOLAR SPECTRUM.

Element.	Atomic Weight.	Number of Lines Identified.	$\frac{\text{Intensity Flash.}}{\text{Intensity Solar Lines.}}$	$\frac{\text{Number of Lines Identified.}}{\text{Total Number of Lines.}}$
Na	23.0	—	—	—
Mg	24.3	1	0.10	1.00
Al	27.1	—	—	—
Ca	40.0	8	0.34	0.38
GROUP II. LINES STRONG IN FLASH, WEAK IN SOLAR SPECTRUM.				
Sc	44.1	6	0.81	0.75
Ti	48.1	62	0.68	0.70
V	51.2	15	0.68	0.67
Cr	52.1	38	0.55	0.69
Mn	55.1	27	0.24	0.48
Sr	87.6	2	1.08	0.67
Y	88.7	2	0.50	0.67
Zr	90.6	9	0.46	0.70
GROUP III. LINES WEAK IN FLASH, STRONG IN SOLAR SPECTRUM.				
Fe	56.0	125	0.20	0.32
Ni	58.7	9	0.36	0.28
Co	59.0	6	0.19	0.29

Looking at the numbers in the last two columns, we see that the lines naturally fall into three groups, as given in the above table.

To these may also be added the following lines:—

La, atomic weight 138.5, 3 lines at λ 4123.384, λ 4217.720 and λ 4613.544.

Ba, atomic weight 137, 1 line, at λ 4554.211; and the following lines possibly identified:

Si, atomic weight 12, 1 line, at λ 3905.660.

Zn, atomic weight 65, 1 line, at λ 4810.724.

Ce, atomic weight, 92, 2 lines at λ 4003.912 and λ 4107.649.

In Group I would also fall *Al*, if we consider the relative intensities of the two lines λ 3944.160 and λ 3971.674; and undoubtedly *Na*, if our plate took in the D lines.

The grouping of these lines is exactly that adopted by EVERSHED from his investigations of the Indian eclipse, except that I have put *Zr* with *Sr* and *V* in Group II. *Mn* seems to represent the transition from Group II to Group III.

Sir WILLIAM and Lady HUGGINS* called attention to the great heights to which *Ca* extends in the Sun's atmosphere, and it is on account of this great extent that H and K are such prominent lines, not only in the absorption spectrum, but in the emission spectrum. As EVERSHED† has pointed out, the remarkable variations of the relative intensities in the flash and Fraunhofer spectra are undoubtedly due to the *heights* to which the vapors of the different metals ascend in the chromosphere. We would naturally expect that these heights vary according to the atomic weights of the metals, those of least atomic weights ascending to the greatest distances; and, generally speaking, this no doubt is true. But if we have two gases in the Sun's atmosphere,—one a gas with an intrinsic brightness 1 and a layer 100 miles in thickness,—on the photograph there would result a line in the flash spectrum just as bright as for the other gas of intrinsic brightness 100 and only 1 mile thick, if the Sun and Moon were relatively at rest during the period of the "flash"; but considering the gradual advance of the Moon in covering successive layers of the Sun's atmosphere, we see that in the emission spectrum the photographic brightness of the fainter gas would be many times that of the brighter. The absorption caused by a gas depends on the total number of molecules the solar ray comes in contact with, and will be very nearly equal in the two cases.

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* Sir WILLIAM and Lady HUGGINS, "The relative behavior of the H and K lines of the spectrum of calcium," *Astrophysical Journal*, Vol. 6, 77, 1897.

† EVERSHED, "Wave-length determinations and general results obtained from a detailed examination of spectra photographed at the solar eclipse of January 22, 1898," *Phil. Trans. Royal Society*, A, Vol. 197, 381-413, 1901.

In view of these considerations, it would therefore seem that the gases of the metals of Group II extend very high, that they are nowhere very much condensed, and that practically all the gas contributes to the formation of the emission line; and hence the flash lines are to be regarded as true reversals of the corresponding solar lines.

The vapors of Groups I and III are somewhat condensed near the Sun's surface (those of Group I, particularly *Ca,* reach far greater heights than those of Group III), but as it is the upper portions that contribute most to the formation of the emission lines, owing to the progressive motion of the Moon, the flash lines are to be regarded as only partial reversals of the Fraunhofer lines, the solar intensities being greater than the flash intensities.

Taking account of lines in the flash identified with groups in the solar spectrum, about half the solar lines have corresponding lines in the flash. From the above considerations, we see that it is highly improbable that lines of intensity 2 on ROWLAND'S scale in the solar spectrum, and belonging to Groups I and III, will have flash lines corresponding to them of sufficient brightness to show in this flash. In fact, although there are 135 *Fe* lines of intensity 2 between F and H, only eleven of these are found in the flash; and, indeed, great numbers of the feebler solar lines are lacking in the flash. But if, on the other hand, we compare the stronger lines, we see that every strong line of the solar spectrum is almost without exception found in the flash spectrum.

And so, remembering the meaning of the differences of intensities, we see no reason for giving up our faith in the existence of the " reversing layer."

We may obtain an approximate estimate of the depths of the layers producing the bright arcs by measuring the angular extent of the arcs. Accordingly, the lengths of some of the more conspicuous bright lines have been measured, and thence were deduced the elevations of the luminous layers producing the bright lines of the flash spectrum. In calculating, the semi-diameter of the Sun was taken as 948″.4, and the Moon's augmented semi-diameter 1013″.8. For the purposes of comparison, the same arcs were taken that Frost* has measured. The depths of the luminous layers of the various metallic vapors come out as follows:—

Spectrum line...	*H* 3970	*He* 4026	*Sr* 4078	*Hδ* 4102	*Sr* 4215	*Ca* 4226	*Sc ?* 4247	*Fe pair* 4250	*Cr* 4254
Approximate height of layer	8″	4″	4″	7″	4″	2″.5	2″.5	< ½″	2″.5

Spectrum line...	*Cr* 4274	*Sc* 4321	*Hγ* 4340	*Ti* 4395	*He* 4471	*Ti* 4501	*Ti* 4549	*Ba* 4554	*Hβ* 4861
Approximate height of layer	2″	2″	8″	2″	7″	2″	2″	2.″5	8″

Comparing these heights with the intensities given in my scale (0—10), it is seen that, roughly speaking, the height in seconds of arc is 0.8 of the value of the intensity for Group II, and 0.4 for Groups I and III. The arcs of the great majority of the lines are no longer than the *Fe* pair at λ 4250, which correspond to an extent of ½″.

As a result we may safely infer that the average depth of the "reversing layer" is about 1″, although from the above considerations we see that the heights to which the gases extend and their condensations are different for the different elements.

These results differ materially from those of Sir Norman Lockyer. He lays great stress on the fact that great numbers of "enhanced" lines, or lines stronger in the spark than in the arc spectrum, are found in the spectrum of the chromosphere. In order to investigate this idea, close comparisons were made between the above flash lines and the latest list of "enhanced" lines given by Lockyer in *Proc. R. S.*, Vol. 65, 452, 1900.

Taking up first titanium, as the "enhanced" lines for this metal are most numerous, it is found that he has given fifty-three lines between λ 3900 and λ 4590. This region is all included in the photographs of the flash. Thirty out of the fifty-three "enhanced" lines certainly appear as bright lines in the flash, eleven do not appear, the other twelve are doubtful, from their proximity to strong flash lines, or from their being situated in a group in the flash. Thus 56 per cent of the "enhanced" lines of *Ti* are found as chromosphere lines; and this would seem to strongly support LOCKYER'S views. But, on the other hand, every one of these thirty lines, without exception, appears as a strong line in the solar spectrum; and the coincidence between "enhanced" and flash lines does not prove anything definite, for where there are strong Fraunhofer lines we expect strong reversals in the flash. A real test would be the case where there is a strong "enhanced" line, but no strong solar line corresponding to it. Such a line occurs in titanium at λ 4308.60, where the intensity in the spark is 7, and on the same scale in the arc 1-2. There is a line in ROWLAND'S tables at λ 4308.601 with an intensity of 00, but there is certainly no exceptionally strong flash line which we would be led to expect if LOCKYER'S idea is correct. The appearance of this line may be contrasted with that at λ 4563.94. Both have the same intensity in the spark (*loc. cit.*), but to λ 4563.94 corresponds a strong line of intensity 4 on ROWLAND'S scale, and a strong reversal in the flash of intensity 5 on my scale.

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* *Astrophysical Journal*, Vol. 12, 346, 1900.

The conclusions from the "enhanced" lines of iron agree with those for titanium, *i. e.* there are a great number of strong lines in the flash spectrum corresponding to the "enhanced" lines, but they also correspond to strong Fraunhofer lines.

A severe test of the idea that "enhanced" lines are found with great frequency in the spectrum of the chromosphere will be given by the metal vanadium. LOCKYER gives twenty-five lines between λ 3885.05 and λ 4243.10, the majority of which are decidedly stronger in the spark than in the arc. Only four of these lines are with certainty found in the flash, corresponding to LOCKYER'S lines at λ 4005.85, λ 4035.80, λ 4225.41, and λ 4243.10. The first two of these have corresponding strong solar lines; the second two have not; none of the four lines, however, are identified by ROWLAND as due to vanadium. Three out of nineteen "enhanced" lines of manganese are found in the flash.

From these comparisons it would seem that there is no close connection between "enhanced" lines and the bright lines of the chromosphere seen in the flash.

When several reasons are advanced to explain the same phenomenon, that one is most readily accepted which is the simplest, which most easily follows the observed facts, and which tends to fewest or no contradictions. Three different explanations are given for the flash spectrum. The first is the original idea of YOUNG's,—that the chromospheric spectrum is merely the flashing out of the reversing layer, the differences of intensities being easily explainable by the different heights to which the layers of the different vapors extend above the Sun's surface. The prominence of "enhanced" lines in the flash spectrum does not seem to be quite as pronounced, from the above investigations, as LOCKYER would have us believe, and there seems, therefore, no solid foundation for the idea that the flash spectrum is at a higher temperature than that of the Fraunhofer spectrum, even if it is farther away than the "reversing layer" from the hot Sun towards the cold of interstellar space. The difficulties in the way of accepting the explanation of JULIUS, as given in the *Astrophysical Journal* for February, 1902, are that we so far have been able to find in the laboratory anomalous dispersion for only one metal, sodium, (although this does not say it may not be found for others); that no photographs have shown the doubling of the lines in the flash spectrum, except those of tne Dutch party at the Sumatra eclipse, and that the doubling, if seen, could be so much more easily explained from the lack of perfect focus.

Taking all things into consideration, it seems much easier to explain the flash spectrum, as did Professor YOUNG, as a reversal of the Fraunhofer spectrum.

COLUMBIA UNIVERSITY, May 15, 1902.

SOME NEW ASTRONOMICAL INSTRUMENTS.

BY FRANK SCHLESINGER.

I. THE REGISTERING MICROMETER.—The greatest obstacle in the way of more accurate determinations of Right Ascensions is the observer's personal equation, which causes him to estimate the time of a star's transit always too early or always too late. Were the personal equation constant for each observer for a reasonably long period, things would not be so bad; but it has been known to vary in the course of a single night, besides depending upon the brightness of the observed object, and even upon the steadiness of the atmosphere. REPSOLD, the head of